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Gain Measurements on a Prototype NIF/LMJ Amplifier Pump Cavity

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Abstract

We are currently developing large-aperture amplifiers for the National Ignition Facility (NIF) and Laser Megajoules (LMJ) lasers. These multi-segment amplifiers are of the flashlamp-pumped, Nd:Glass type and are designed to propagate a nominally 36 cm square beam. The apertures within a particular amplifier bundle are arranged in a four-high by two-wide configuration and utilize two side flashlamp arrays and a central flashlamp array for pumping. The configuration is very similar to that used in the Beamlet laser, a single-beam prototype for the NIF/LMJ lasers, which has four apertures arranged in a two-high by two-wide configuration.

In designing these amplifiers, one of the more important criteria is the layout and composition of the pump cavity. The pump cavity consists of the laser slab, blast shields, flashlamp cassettes, and any high-reflectivity components that may be used. The current pump cavity design for the NIF/LMJ lasers is in many respects very similar to that of the Beamlet laser: Brewster-angle laser slab, central and side flashlamp cassettes, and top and bottom reflectors (in both the flashlamp cassettes and in the slab cassette). However, there are a number of important differences between the two amplifiers. The NIF/LMJ amplifiers will use 180 cm arc-length, 4.3 cm bore-diameter flashlamps as opposed to the 91 cm arc-length, 2.5 cm bore diameter flashlamps used on Beamlet. In addition, in the NIF/LMJ lasers there will be eight lamps in the central lamp array and six lamps in the side lamp array, *vs* 16 lamps in the central array and 10 lamps in the side array on Beamlet. Finally, the NIF/LMJ flashlamp pulsewidth will be 360 μs as compared to 550 μs on Beamlet.

To understand the effect of these differences, we performed a series of experiments in order to characterize the optical performance of the amplifier. These experiments were done on a Beamlet amplifier that was modified to accept the different-sized flashlamps. In addition, our pulsed-power bank was modified to produce the 360 μs pulsewidths needed. We will present results regarding the full-aperture gain distribution and the effect of pre-pulse conditions on flashlamp pumping efficiency. We also investigated the possibility of steering the pump light to selected regions of the laser slab. We will show that this can ameliorate the effects of amplified spontaneous emission on gain uniformity.

2. The Modified Beamlet Amplifier

A plan view of our modified Beamlet amplifier (MBA) is shown in Fig. 1, along with a list of important parameters and their values for the MBA and NIF amplifiers. In most respects the two amplifiers are similar, the primary difference being the height of the amplifier: two slabs high for the MBA *vs* four slabs high for NIF. Since there is a strong vertical symmetry in the amplifier due to the presence of top and bottom reflectors, we believe that the results obtained with our two-high amplifier will not be significantly different than those obtained with a four-high NIF prototype. Another difference is the slab thickness: our MBA used 3.4 cm-thick slabs, whereas the NIF will use 4.1 cm-thick slabs. This difference is taken into account with our ray-trace codes when predicting NIF amplifier performance.

Another feature of our MBA is the ability to test one or two-wide amplifiers. This is important when testing the amplifier with two central arrays, as our pulse-power system limits the number of lamps we may fire to 20. To test central-central pumping, we placed absorbing architectural glass and a diffuse metal reflector behind the central lamp array to simulate an adjacent module. By comparing the aperture-averaged gain coefficients with two-wide and one-wide modules, we have found that the two configurations produce the same gain coefficient to within 0.1 %/cm.

3. Experimenal results and discussion

In a laser chain, a given slab can occupy one of two positions: 1) an interior position, where the slab is located between two others, or 2) an end position, where the slab is located at the end of the chain. An end slab may take on two further configurations, "X" or "Diamond," which refers to the shape the two end slabs make (see Fig. 2). An interior position is difficult to access experimentally, thus to obtain the gain coefficient for this location, we take data in the "Diamond," "X," and "V" configurations as shown in Fig. 2. We use the aperture-averaged gain coefficient obtained in these three configurations in our bulk-gain model[1] to determine a relative cavity transfer efficiency for each configuraton. The cavity transfer efficiency is a measure of the amount of light leaving the flashlamps that is incident on the laser slab. It may be shown that the cavity transfer efficiency for an interior configuration may be given as:

$$\eta_i = \eta_d + \eta_x - \eta_v \qquad (1)$$

where η_d, η_x, and η_v are the cavity transfer efficiencies for the "Diamond," "X," and "V" configurations respectively. It should be noted that a "V" configuration does not exist in a real laser chain, but is used here only as a step in determining the cavity transfer efficiency for an interior slab. The value of η_i obtained from Eq. (1) is then used in our bulk-gain model to determine the gain coefficient for an interior slab.

Once we find the gain coefficients for the interior, "Diamond," and "X" configurations, the average gain coefficient for a chain N (odd) slabs long is given by:

$$\alpha_N = [(N-2)\alpha_i + \alpha_d + \alpha_x] / N \qquad (2)$$

where α_i, α_d, and α_x are the gain coefficients for the interior, "Diamond," and "X" configurations respectively.

In Fig. 3, we show the two-dimensional gain coefficient contours for an interior slab at an explosion fraction of 0.2. For this case, the aperture-averaged gain coefficient is 5.1 %/cm but the peak-to-average ratio of the gain coefficient, $\alpha_{pk} / \langle\alpha\rangle$, is 1.09:1, indicating a large degree of gain non-uniformity. It is desirable to have a uniform gain profile since the energy requirements for the front-end of the laser system are lower than for amplifiers with a high degree of gain non-uniformity. The gain non-uniformity depicted in Fig. 3 is due primarily to amplified spontaneous emission (ASE) that is trapped within the laser slab. Amplified spontaneous emission tends to depump the upper laser level, leading to lower gain near the edges of the aperture. This is clearly shown in Fig. 4, which shows the horizontal gain profile at various explosion fractions. At low explosion fractions, ASE effects are small and the gain distribution is very uniform. At higher explosion fractions, notably $f_x = 0.2$ and 0.25, ASE effects are quite noticable and cause the characteristic roll-off in gain near the edges of the aperture.

4. Reduction of ASE effects and comparison with computer models

The issue now is how best to reduce the effects of ASE. Since the gain is lower near the edges of the aperture, one thought that comes to mind is to increase the pump rate in those areas. To avoid exacerbating the front-to-back pump asymmetry that drives pump-induced wavefront distortions, it is desirable to direct pump light to the side of the aperture farthest away from the flashlamps.

For the case of central arrays, this may be done as shown in Fig. 5. The reflectors between the lamps are shaped so that their sides are sections of ellipses, with one focus situated at the center of the lamp, and the other focus at a desired "target point" on the laser slab. We have discovered that the curved surfaces may be approximated by straight lines with little change in performance. With this alteration, we greatly simplify the manufacturing process.

We experimenatlly tested this concept with the pump cavity shown in Fig. 6. As may be seen, the reflector shapes between the lamps vary from position to position so that the light may be directed to different points on the slab. The lines emanating from the lamps indicate the target points on the slab. The results of this experiment are shown in Fig. 7. This figure shows the horizontal gain profile for an interior slab at an explosion fraction of 0.2. Two cases are shown: 1) simple diamond reflectors between the flashlamps (baseline case) and 2) skewed diamond reflectors (as shown in Fig. 6) between the lamps. As may be seen, by directing the pump radiation to areas of lower gain, the effects of ASE are reduced and the gain at the edges of the aperture are increased approximately 15%. As indicated on the figure, we achieved a two-fold improvement in gain uniformity with essentially no reduction in the average gain coefficient.

In order to evaluate various pump cavity geometries in an efficient manner, we have developed a 2-D ray-trace code[2] that predicts the two-dimensional gain distribution in the aperture. Fig. 8 shows the comparison between our measurements on the MBA and our code predictions at four explosion fractions. As may be seen, we obtain good agreement between our code and the measurements. It is interesting to note that the gain profile is indicative of the pump profile at low explosion fractions. An examination of the data at an explosion fraction of 0.1 indicates more pump light near the edges of the aperture than at the center, as desired.

With our ray-trace code, we have recently designed a pump cavity for central/side pumping. This pump cavity is shown in Fig. 9 and uses involutes in the side array for high efficiency and skewed diamond reflectors in the central array to direct the pump light to the desired region of the slab. The gain profile as predicted with our code for this configuration is shown in Fig. 10. As may be seen, the gain uniformity is improved with essentially no reduction in the average gain coefficient.

5. Measurements with LG-770 laser glass

We have recently measured the gain with LG-770 laser glass, one of the two laser glasses proposed for the NIF laser. This is a relatively new glass and there is little information on its behavior in multi-segment amplifiers. We measured the gain of the slab in a central/side pumping configuration and compared the results with an LG-750 laser slab (the kind presently in use on the Beamlet laser). Both slabs had the same dimensions and doping levels, thus affording a direct comparison. The results of this measurement are shown in Fig. 11. As may be seen, the LG-770 slab has about a 6% greater gain coefficient (at an average gain coefficient of .05 cm^{-1}) than the LG-750 slab. It should be noted that due to the presumed higher stimulated emission cross section, the stored energy density is approximately 3% less in LG-770 than LG-750. This may be an issue for long-pulse operation of the NIF, where high extraction efficiencies are attained.

6. Summary

We are developing pump cavities for the NIF/LMJ lasers using a modified Beamlet amplifier as a testbed. Using this amplifier, we have experimentally demonstrated in a central/central pumping configuration that gain roll-off due to ASE within the laser slab may be reduced by directing pump radiation to the edges of the aperture. This may be done by shaping the reflectors between the flashlamps in the central array We have found that the data is in good agreement with the predictions of our 2-D ray trace code, and we are using the code to develop pump cavities that deliver high efficiency and uniform gain in a central/side pump configuration. Measurements with an LG-770 laser slab indicate that at an average gain coefficient of .05 cm^{-1}, LG-770 produces a 6% higher gain coefficient than LG-750 laser glass.

7. References

[1] H.T. Powell, A.C. Erlandson, K.S. Jancaitis, and J.E. Murray, "Flashlamp Pumping of Nd:Glass Disk Amplifiers," SPIE 1277, p.103, 1990.
[2] G. LeTouzé, Olivier Cabourdin, J.F. Mengue, M. Rotter and K. Jancaitis. "Shaped reflectors for Pump Cavities," 2nd Annual Conf. Solid State Lasers for Application to ICF. Limeil, France 1996

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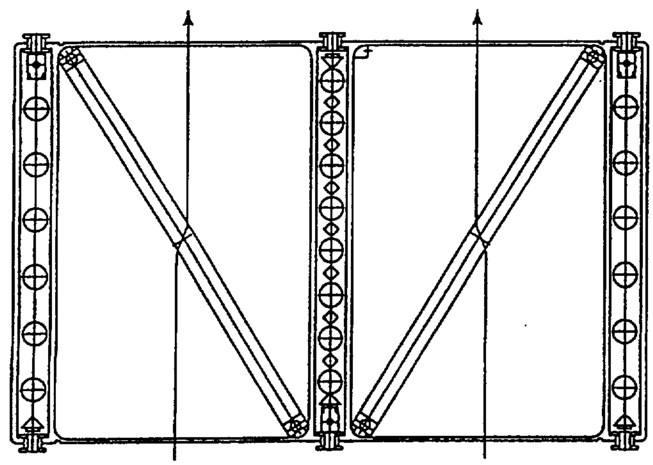
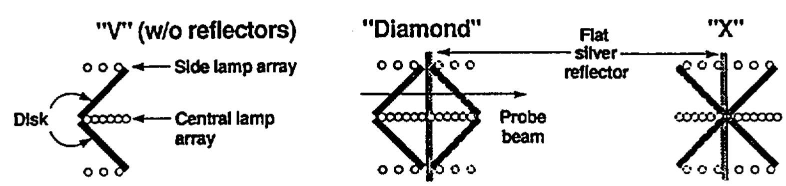


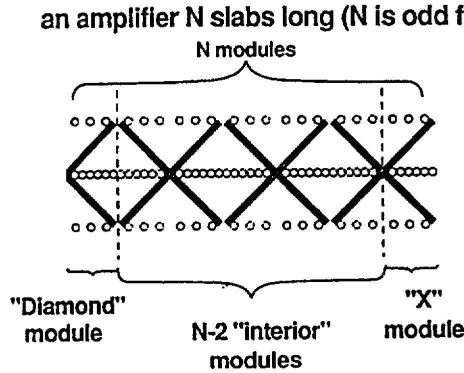
Parameter	MBA	NIF
Apertures		
– # vertical	2	4
– # horizontal	1 or 2	2
– # size (cm)	39 x 39.5	40.2 x 40.2
Flashlamps		
– bore dia. (cm)	4.3	4.3
– length (cm)	91	180
– pulsewidth (μs)	390	360
Laser Slab		
– length (cm)	78.3	80.0
– height (cm)	44.4	45.7
– thickness (cm)	3.4 or 4.0	4.1

Figure 1. Plan view of Modified Beamlet Amplifier (MBA) and comparison to NIF/LMJ amplifiers.

- Three different pump cavity configurations were tested:



- The data were extrapolated to predict the gain coefficients of an amplifier N slabs long (N is odd for uniform gain)



$\eta_{interior} = \eta_{diamond} + \eta_x - \eta_v$

$$\alpha_n = \frac{[(N\text{-}2)\,\alpha_{interior} + \alpha_{diamond} + \alpha_x]}{N}$$

Figure 2. How a one-slab-long amplifier is used to obtain gain coefficients for a given position in a laser chain.

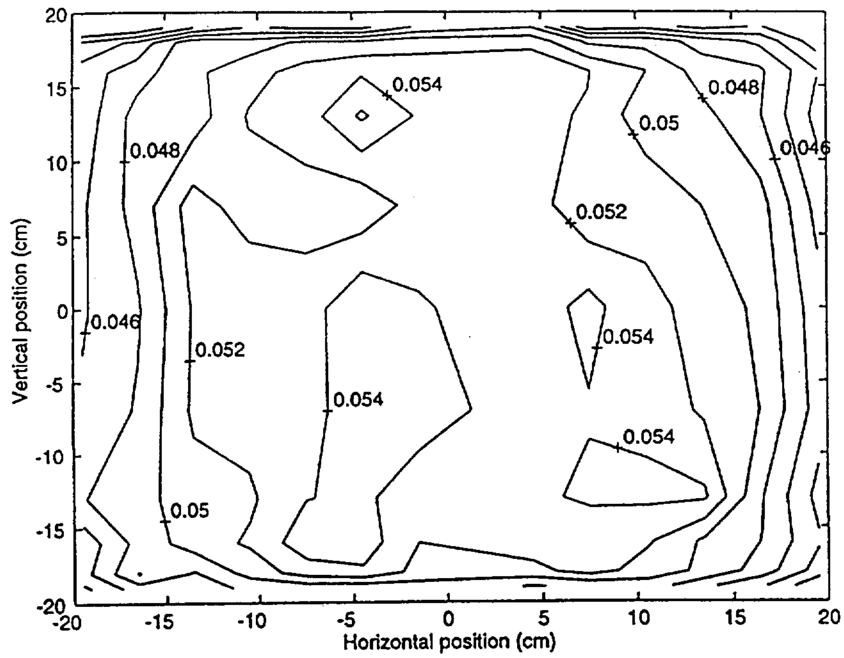


Figure 3. Measured MBA gain coefficient (in cm^{-1}) for an interior slab at $f_x = 0.2$.

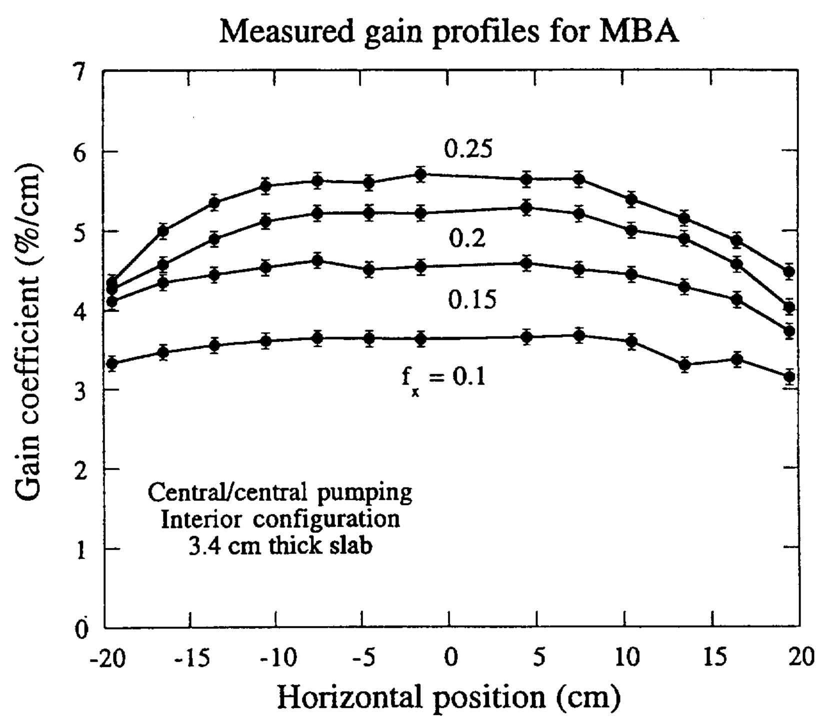


Figure 4. Measured MBA gain profiles as a function of explosion fraction. Note effect of ASE at higher explosion fractions.

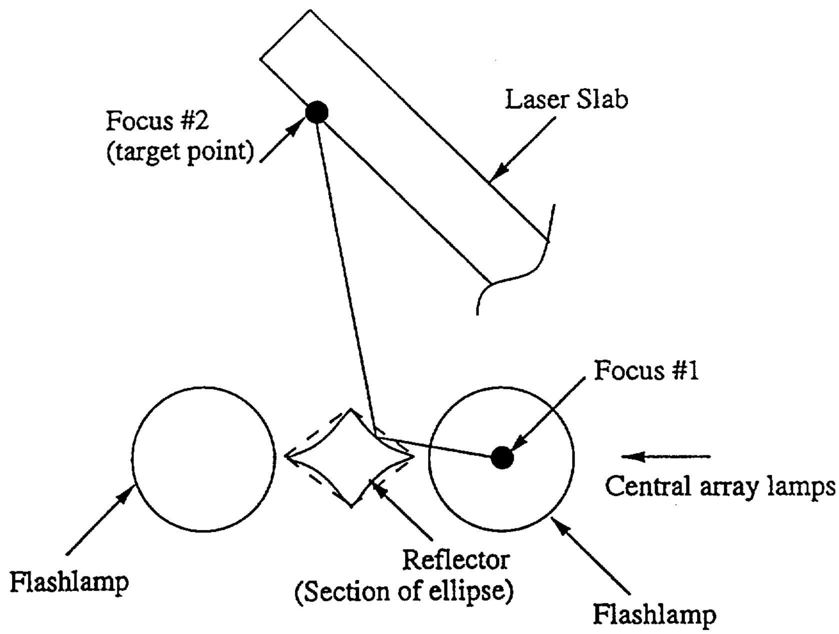


Figure 5. Schematic of shaped-reflector concept to reduce effects of ASE.

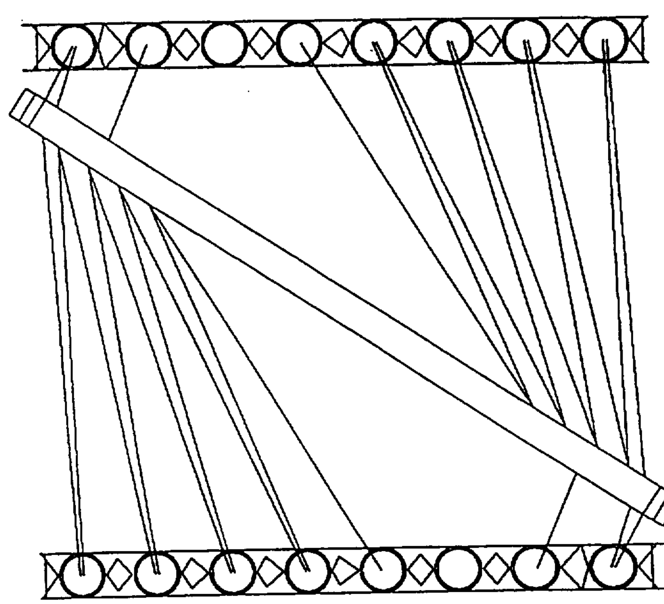
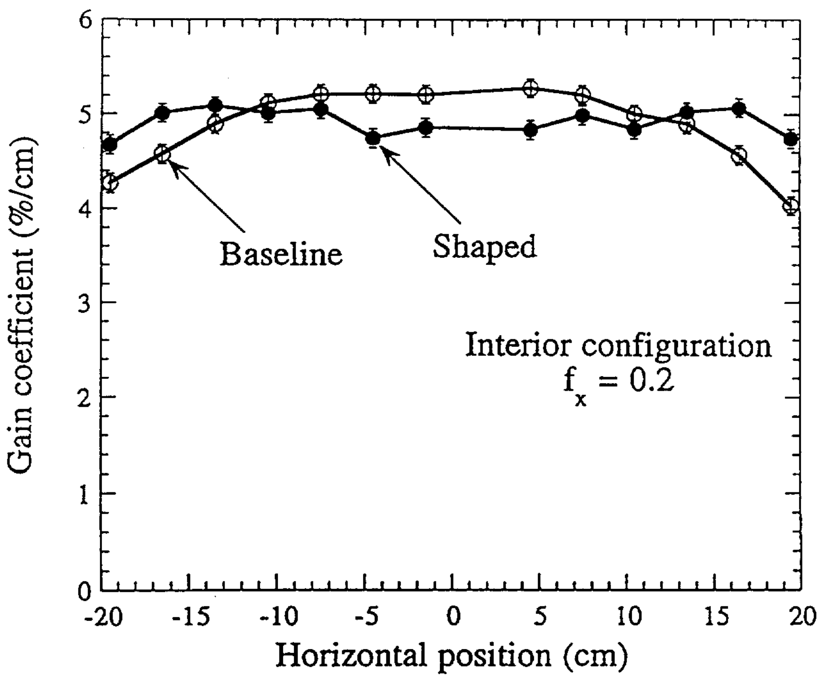


Figure 6. MBA pump cavity built and tested with shaped reflectors. Lines indicate target points on the slab to which pump light was directed.



- Uniformity was improved

$$\left(\frac{\alpha_{pk}}{\langle\alpha\rangle}\right)_{base} = 1.06$$

$$\left(\frac{\alpha_{pk}}{\langle\alpha\rangle}\right)_{shape} = 1.03$$

- Ave. gain coefficient was unchanged

$$\langle\alpha\rangle_{base} = 4.99 \pm 0.07 \text{ %/cm}$$

$$\langle\alpha\rangle_{shape} = 4.95 \pm 0.1 \text{ %/cm}$$

Figure 7. Comparison of gain-coefficient profiles using simple diamond and skewed diamond reflectors between flashlamps in central/central pumping.

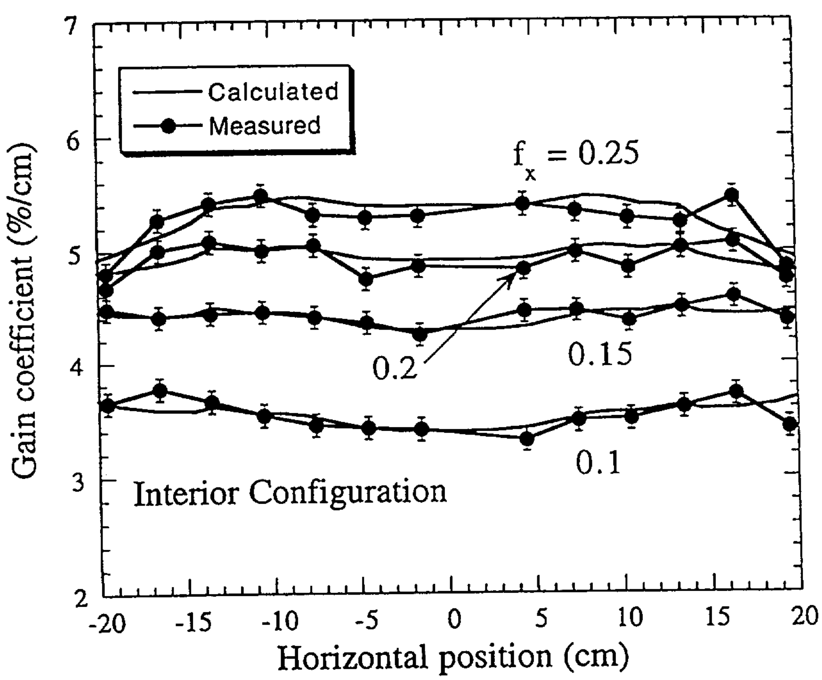


Figure 8. Comparison of measurements and ray-trace code predictions for a variety of explosion fractions. At low explosion fractions, the gain profile is indicative of the pump profile.

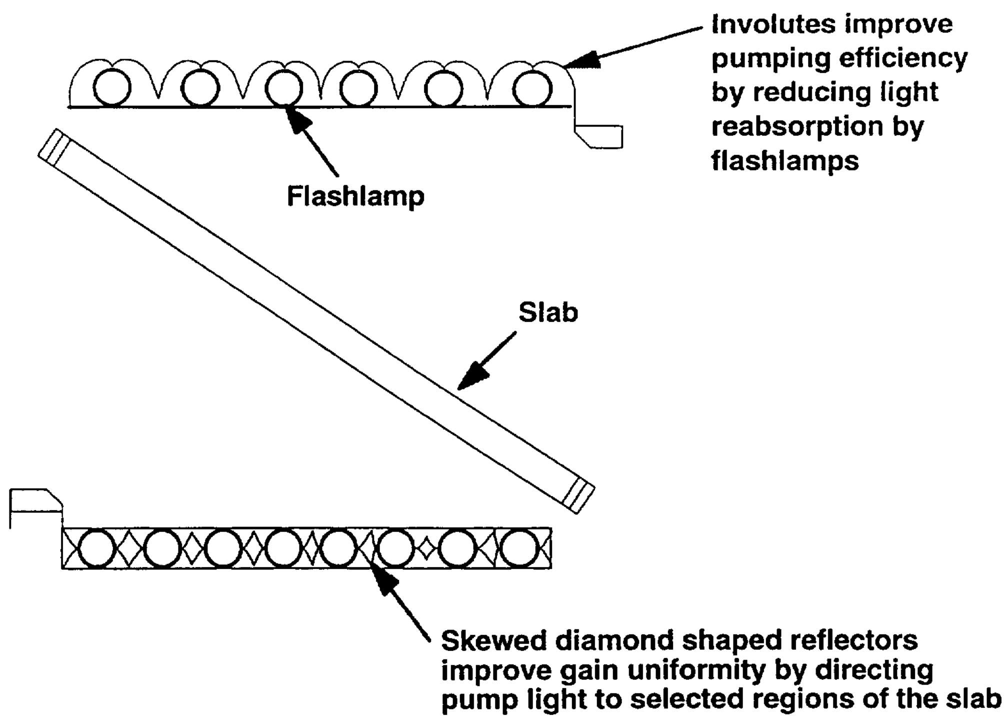
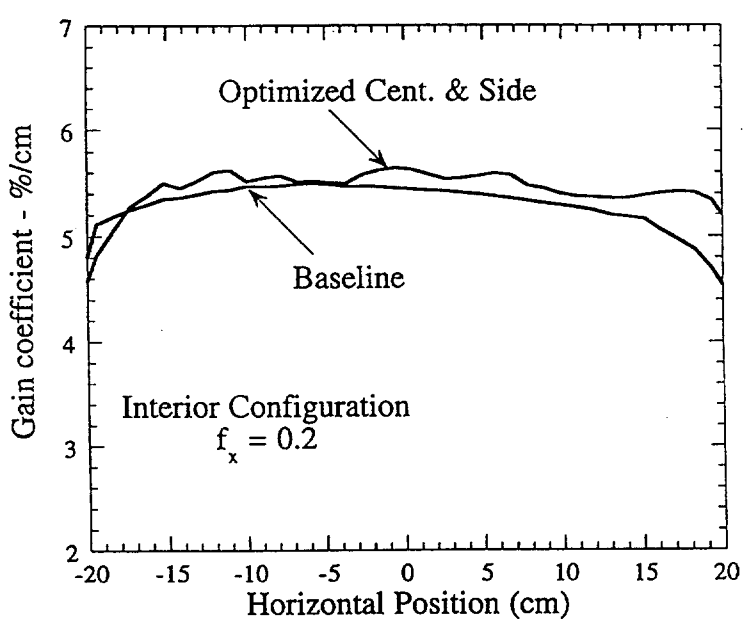


Figure 9. Plan view of pump cavity for central/side pumping. The side array uses involutes for high efficiency.



- Uniformity was improved

$$\left(\frac{\alpha_{pk}}{\langle\alpha\rangle}\right)_{base} = 1.040$$

$$\left(\frac{\alpha_{pk}}{\langle\alpha\rangle}\right)_{opt} = 1.026$$

Figure 10. Predicted gain profiles for central/side pumping. The baseline case uses flat reflectors in the side array and simple diamond reflectors in the central array. The optimized case uses the pump cavity shown in Figure 9.

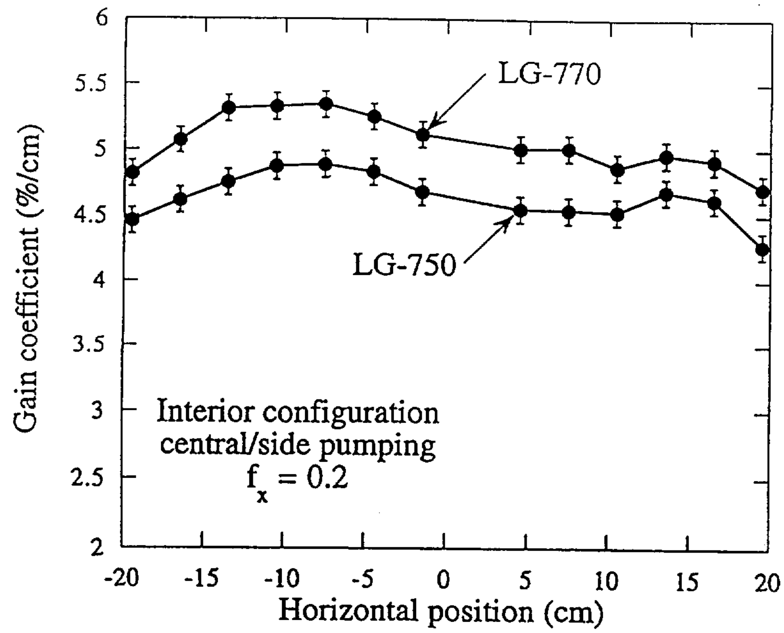


Figure 11. Gain profile comparison of LG-750 and LG-770 laser glass.